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<b>(21) International Application Number:</b> PCT/IL99/00500 <b>(22) International Filing Date:</b> 14 September 1999 (14.09.99) <b>(30) Priority Data:</b> 60/100,632                      16 September 1998 (16.09.98)      US <b>(71) Applicant (for all designated States except US):</b> JOLT LTD. [IL/IL]; Hamarpeh Street 8, 97774 Jerusalem (IL). <b>(72) Inventors; and</b> <b>(75) Inventors/Applicants (for US only):</b> MEDVED, David [IL/IL]; Marcus Street 18, 92233 Jerusalem (IL). DAVIDOVICH, Leonid [IL/IL]; Givat Hamatos Street 72/1, 91000 Jerusalem (IL). <b>(74) Agent:</b> FREIDMAN, Mark, M.; Beit Samueloff, Haomanim Street 7, 67897 Tel Aviv (IL).		<b>(81) Designated States:</b> AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).  <b>Published</b> <i>Without international search report and to be republished          upon receipt of that report.</i>
<b>(54) Title:</b> WIRELESS OPTICAL COMMUNICATIONS WITHOUT ELECTRONICS  <b>(57) Abstract</b>  <p>A system for exchanging optical signals between two separate locations. Each location is provided with a transceiver that includes a transmitter and a receiver. Both the transmitter and the receiver are based on a transceiver unit, used as a transmitter unit in the transmitter and as a receiver unit in the receiver. The transceiver unit includes a multimode optical waveguide and imaging optics that collimates the light emerging from the waveguide in the transmitter implementation of the unit and that focuses incoming light onto the waveguide in the receiver implementation of the unit. The waveguide is terminated by a FC/APC to suppress reflections at the waveguide/air interface. In each transceiver, the units are mounted in clusters, with their optical axes all parallel. Transmitter units of a transmitter cluster are optically coupled via a splitter to a common input waveguide, possibly via one or more optical amplifiers. Receiver units of a receiver cluster are optically coupled via a combiner to a common output waveguide. Alternatively, the receiver includes an airlink receiver to convert incoming optical signals to electronic signals and a converter unit to convert the electronic signals back to optical signals. The common waveguides in turn are optically coupled to network interface units at each location. Transceivers are aimed at each other to exchange optical signals between the two locations.</p>		

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## WIRELESS OPTICAL COMMUNICATIONS WITHOUT ELECTRONICS

FIELD AND BACKGROUND OF THE INVENTION

The present invention relates to wireless communications systems in general,  
5 and more particularly to optical wireless communications systems.

Medved et al., in U. S. Patent No. 5,818, 619, which is incorporated by  
reference for all purposes as if fully set forth herein, teach a wireless communications  
system for linking different parts of an optical communications network. Each part of  
the network is provided with one or more optical communications network interface  
10 units and with universal converter units that are optically coupled to their respective  
network interface units. Each universal converter unit includes an airlink transmitter,  
an airlink receiver, a fiber optic receiver and a fiber optic transmitter. The fiber optic  
receiver receives outgoing optical signals from the network interface unit and  
transforms these optical signals to electronic signals. These electronic signals are sent  
15 to the airlink transmitter, where these electronic signals are transformed back to  
optical signals and transmitted as such into free space. The airlink receiver receives  
optical signals that were transmitted into free space by another universal converter  
unit and transforms these incoming optical signals into electronic signals. These  
electronic signals are sent to the fiber optic transmitter, which transforms these  
20 electronic signals back to optical signals that are sent to the network interface unit via  
a fiber optic cable. The network interface units and the universal converter units are  
operated in pairs, with each member of the pair being a portion of a different optical  
communications network or of a different part of the same optical communications  
network. The airlink transmitter of each universal converter unit is aimed at the airlink  
25 receiver of the other universal converter unit to enable exchange of optical signals  
between the two optical communications network or between the two parts of the  
same optical communications network.

The wireless communications system of Medved et al. is intended for use in an  
optical communications network in which signals are encoded in a single carrier  
30 wavelength. Recently, optical communications networks based on dense wavelength  
division multiplexing (DWDM) have been introduced. In a DWDM network, several

carrier wavelengths are multiplexed on the same optical fiber. The data transmission rate available using DWDM would overwhelm the electronics of the universal converter units of Medved et al. In any case, the various carrier wavelengths would have to be demultiplexed, and a separate network interface unit and universal  
5 converter unit would be needed for each carrier wavelength.

There is thus a widely recognized need for, and it would be highly advantageous to have, a system for linking two parts of an optical communications network that are remote from each other in a way that facilitates the exchange of DWDM optical signals.

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#### SUMMARY OF THE INVENTION

According to the present invention there is provided an optical device including: (a) a multimode optical waveguide having a proximal end and a distal end; (b) a single mode optical waveguide having a distal end; (c) a mechanism for optically  
15 coupling the distal end of the single mode optical waveguide to the proximal end of the multimode optical waveguide; and (d) imaging optics, optically coupled to the distal end of the multimode optical waveguide.

According to the present invention there is provided an optical transmitter, including: (a) a common input optical waveguide; (b) a plurality of transmitter optical  
20 waveguides, each transmitter optical waveguide having a distal end; (c) for each transmitter optical waveguide, imaging optics, optically coupled to the distal end of the each transmitter optical waveguide; and (d) a mechanism for optically coupling the common input optical waveguide to the transmitter optical waveguides.

According to the present invention there is provided an optical receiver,  
25 including: (a) a common output optical waveguide; (b) a plurality of receiver optical waveguides, each receiver optical waveguide having a distal end; (c) for each receiver optical waveguide, imaging optics, optically coupled to the distal end of the each receiver optical waveguide; and (d) a mechanism for optically coupling the common output optical waveguide to the receiver optical waveguides.

30 According to the present invention there is provided an optical transceiver including: (a) a transmitter optical waveguide having a distal end; (b) transmitter

imaging optics, having a transmitter optical axis, optically coupled to the distal end of the transmitter optical waveguide; (c) a plurality of receiver optical waveguides, each receiver optical waveguide having a distal end; and (d) for each receiver optical waveguide, receiver imaging optics, having a receiver optical axis, optically coupled to the distal end of the each receiver optical waveguide, the transmitter optical axis and the receiver optical axes all being substantially parallel.

According to the present invention there is provided a wireless communications system, including: (a) a transmitter optical waveguide having a proximal end and a distal end; (b) transmitter imaging optics, optically coupled to the distal end of the transmitter optical waveguide; (c) at least one receiver optical waveguide having a proximal end and a distal end; (d) for each at least one receiver optical waveguide, receiver imaging optics optically coupled to the distal end of the at least one receiver optical waveguide; and (e) an optical communication network interface unit, optically coupled to the proximal ends of the transmitter optical waveguide and of the at least one receiver optical waveguide, for transmitting optical signals to the transmitter optical waveguide and for receiving optical signals from the at least one receiver optical waveguide.

According to the present invention there is provided an optical transceiver including: (a) a transmitter optical waveguide having a distal end; (b) transmitter imaging optics, having a transmitter optical axis, optically coupled to the distal end of the transmitter optical waveguide; and (c) an airlink receiver having a receiver optical axis substantially parallel to the transmitter optical axis.

According to the present invention there is provided a wireless communication system, including: (a) a transmitter optical waveguide having a proximal end and a distal end; (b) transmitter imaging optics, optically coupled to the distal end of the transmitter optical waveguide; (c) an airlink receiver; (d) a converter unit, electrically coupled to the airlink receiver; and (e) an optical communication network interface unit, optically coupled to the proximal end of the transmitter optical waveguide and to the converter unit, for transmitting optical signals to the transmitter optical waveguide and for receiving optical signals from the converter unit.

According to the present invention there is provided an optical device including: (a) an optical fiber having a distal end; and (b) a FC/APC fiber optic connector serving as a reflection-suppressing interface between the distal end and a rarefied optical medium.

5        According to the present invention there is provided a wireless system for transmitting wavelength-multiplexed optical signals from a first location to a second location, including: (a) an optical transmitter, at the first location, the optical transmitter including a multimode input optical waveguide for receiving the optical signals; and (b) an optical receiver, at the second location, for receiving the optical  
10        signals from the optical transmitter.

      According to the present invention there is provided a method for exchanging optical signals between two parts of an optical network, including the steps of: (a) providing each part of the network with: (i) a network interface unit, and (ii) a transceiver including: (A) transmitter imaging optics, (B) at least one transmitter  
15        optical waveguide for optically coupling the network interface unit to the transmitter imaging optics, (C) receiver imaging optics, and (D) at least one receiver optical waveguide for optically coupling the network interface unit to the receiver imaging optics; and (b) aiming the transceivers so that at least part of the optical signals emerging from the transmitter imaging optics of a first the transceiver are intercepted  
20        by the receiver imaging optics of a second the transceiver and so that at least part of the optical signals emerging from the transmitter imaging optics of the second transceiver are intercepted by the receiver imaging optics of the first transceiver.

      According to the present invention there is provided a method for exchanging optical signals between two parts of an optical network, including the steps of: (a)  
25        providing each part of the network with: (i) a network interface unit, and (ii) a transceiver including: (A) transmitter imaging optics, (B) at least one transmitter optical waveguide for optically coupling the network interface unit to the transmitter imaging optics, (C) an airlink receiver, and (D) a converter unit, electrically coupled to the airlink receiver and optically coupled to the network interface unit; and (b)  
30        aiming the transceivers so that at least part of the optical signals emerging from the transmitter imaging optics of a first the transceiver are intercepted by the airlink

receiver of a second the transceiver and so that at least part of the optical signals emerging from the transmitter imaging optics of the second transceiver are intercepted by the airlink receiver of the first transceiver.

The basic idea of the present invention is to eliminate the conversion of optical signals in the universal converter unit to electronic signals and then back to optical signals. Instead, the outgoing optical signals, from one network interface unit in one part of the optical communications network, are launched directly into free space and are received directly by another network interface unit in another part of the optical communications network.

To facilitate the direct exchange of optical signals between the network interface units, each network interface unit is provided with an optical transceiver, based on a transceiver unit that is used either as a transmitter unit or a receiver unit. A basic transceiver unit has an optical fiber terminating at one end of a cylindrical housing and imaging optics at the other end of the housing. The optical fiber is provided with a mechanism, such as a FC/APC, for suppressing reflections at the fiber-air interface. When the transceiver unit is used as a transmitter unit, optical signals launched from the end of the optical fiber are collimated by the imaging optics into a collimated beam. When the transceiver unit is used as a receiver unit, the imaging optics focus optical signals that they intercept onto the end of the optical fiber. Preferably, the optical fiber is a multimode optical fiber so that the beam launched from the optical fiber in transmitter mode has an adequately large divergence angle.

The transmitter units and the receiver units are used in clusters, to overcome scintillation. In a compound transmitter that includes several transmitter units, the optical fibers of the transmitter units are connected to a common input optical fiber by a splitter. In a compound receiver that includes several receiver units, the optical fibers of the receiver units are connected to a common output optical fiber by a combiner. For transmission over distances greater than several hundred meters, it is necessary to amplify the optical signals input to the transmitter, using an optical amplifier such as an erbium-doped fiber amplifier or a semiconductor fiber amplifier. In a compound transmitter, one optical amplifier may be provided for the common

input optical fiber, or each transmitter unit may be provided with its own optical amplifier. In the latter case, because the input and output of an optical amplifier is via a single mode optical fiber, a mechanism such as a FC/APC is provided for coupling the single mode output of each optical amplifier to the multimode optical fiber of the  
5 respective transmitter unit.

To facilitate aiming, the transmitter and receiver units of a transceiver are aligned mutually so that all their optical axes are parallel.

The common output optical fiber of a compound receiver preferably is a multimode fiber. In case the network interface unit is designed to receive single mode  
10 optical input, the common output optical fiber is provided with a passive adapter, such as a graded index lens or a collimator, for coupling the common output optical fiber to the network interface unit. Similarly, the multimode optical fiber of a single-unit receiver is provided in such a case with a similar passive adapter.

As an alternative to all-optical reception, a transceiver of the present invention  
15 may include an airlink receiver and a fiber optic transmitter, as in the prior art universal converter unit. The transmitter of the transceiver remains all-optical.

In the application of the present invention to the exchange of DWDM signals, each network interface unit preferably includes a demultiplexer for demultiplexing the DWDM signals.

20 Although the examples of the present invention described herein are based on optical fibers, it is to be understood that the scope of the present invention includes optical waveguides generally. The wavelengths of the optical signals that fall within the scope of the present invention include infrared, viable, and ultraviolet wavelengths, although the preferred wavelengths are those that are commonly used for  
25 optical communication: wavelengths in the neighborhood of 850 nm, wavelengths in the neighborhood of 1330 nm and wavelengths in the neighborhood of 1550 nm.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The invention is herein described, by way of example only, with reference to  
30 the accompanying drawings, wherein:



FIG. 1 shows two schematic axial cross sections of two variants of a transceiver unit of the present invention;

FIG. 2 is a schematic depiction of a system of the present invention;

FIG. 3 shows three different transceiver unit cluster configurations;

5 FIG. 4 shows a variant of a transmitter cluster that includes optical amplifiers;

FIG. 5 is a schematic depiction of an alternate transceiver of the present invention;

FIG. 6 is a partial schematic depiction of a system of the present invention for exchanging DWDM optical signals.

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### DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is of an optical communications system which can be use to link two widely separated parts of an optical communications network. Specifically, the present invention can be used to exchange DWDM signals between  
15 the two parts of the network.

The principles and operation of optical communications according to the present invention may be better understood with reference to the drawings and the accompanying description.

Referring now to the drawings, Figure 1 illustrates two variants, 10A and 10B,  
20 of a basic transceiver unit 10 of the present invention. Variants 10A and 10B are illustrated schematically, in axial cross section. Both variants are based on a substantially cylindrical housing 12, at the distal end 14 of which are imaging optics, represented as a lens 18, and at the proximal end 16 of which is a multimode optical fiber 20 whose distal end 22 is terminated in a FC/APC 24. Variant 10B includes, in  
25 addition, a single mode optical fiber 28, optically coupled at the distal end 30 thereof to the proximal end 26 of multimode fiber 20 by a FC/APC 32.

Imaging optics 18 define an optical axis 34. When unit 10 is used as a transmitter, optical signals emerge from distal end 22 of optical fiber 20 as a divergent beam of light that is collimated by imaging optics 18 to propagate as a collimated  
30 beam of light in the direction defined by optical axis 34. When unit 10 is used as a receiver, unit 10 is aimed so that imaging optics 18 intercept a portion of an incoming

beam of light that carries optical signals. Imaging optics 18 focuses the incoming light onto distal end 22 of optical fiber 20. The focal length of imaging optics 18 is adapted to the divergence angle of optical fiber 20.

Typically, optical fibers 20 and 28 are made of optically pure glass. Single mode optical fiber 28 typically has a core diameter of 9 microns. Multimode optical fiber 20 typically has a core diameter of 50, 62.5 and 100 microns, most preferably 100 microns. The purpose of FC/APC 24 is to suppress reflections at the air-glass interface at distal end 22 of optical fiber 20. This use of an FC/APC to suppress reflections at an interface between a solid optical fiber and a rarefied optical medium such as air constitutes an independent aspect of the present invention. The purpose of FC/APC 32 is to connect, and to optically couple, optical fibers 20 and 28. An FC/APC is particularly convenient for this purpose because both optical fibers 20 and 28 typically have the same cladding diameter, 125 microns.

Figure 2 is an illustrative schematic depiction of a system of the present invention, for linking two parts of an optical communications network, represented by two network interface units 58L and 58R. Each part of the optical communications network is provided with a transceiver 36 that includes a transmitter 38 and a receiver 40. Transmitter 38 includes a cluster of three transceiver units 10 configured as transmitter units 42. Each transmitter unit 42 includes a transmitter optical fiber 50 and a transmitter optical axis 46. Receiver unit 40 includes a cluster of three transceiver units 10 configured as receiver units 44. Each receiver unit 44 includes a receiver optical fiber 52 and a receiver optical axis 48. In variant A of transmitter unit 42, transmitter optical fiber 50 is multimode optical fiber 20. In variant B of transmitter unit 42, transmitter optical fiber 50 is the combination of multimode optical fiber 20 and single mode optical fiber 28, coupled by FC/APC 32. Similarly, in variant A of receiver unit 44, receiver optical fiber 52 is multimode optical fiber 20, and in variant B of receiver unit 44, receiver optical fiber 52 is the combination of multimode optical fiber 20 and single mode optical fiber 28, coupled by FC/APC 32. As noted below, it is preferred that receiver units 44 be variants A of transceiver units 10. Transmitter optical fibers 50 are optically coupled, at proximal ends 51 thereof, to the distal end 65 of a common input optical fiber 64, by a splitter 54. Receiver optical

fibers 52 are optically coupled, at proximal ends 53 thereof, to the distal end 67 of a common output optical fiber 66. Common input optical fiber 64 is optically coupled, at the proximal end 61 thereof, to a fiber optic transmitter 60 of network interface unit 58. Common output optical fiber 66 is optically coupled, at the proximal end 63 thereof, to a fiber optic receiver 62 of network interface unit 58.

Transmitter units 42L and receiver units 44L are mounted so that optical axes 46L and 48L all are parallel. Similarly, transmitter units 42R and receiver units 44R are mounted so that optical axes 46R and 48R all are parallel. In use, transceiver 36L is aimed at transceiver 36R, so that the collimated beams of light emitted by transmitter units 42L are at least partly intercepted by receiver units 44R and so that the collimated beams of light emitted by transmitter units 42R are at least partly intercepted by receiver units 44L. Optical signals transmitted by network interface unit 58L via transmitter 60L are conveyed, via optical fibers 64L and 50L and splitter 54L, to transmitter units 42L, where these optical signals are launched into free space, as collimated beams of light, towards transceiver 36R. At transceiver 36R, the optical signals received by receiver units 44R are conveyed, via optical fibers 52R and 66R and combiner 56R, to receiver 62R of network interface unit 58R. Meanwhile, optical signals transmitted by network interface unit 58R via transmitter 60R are conveyed, via optical fibers 64R and 50R and splitter 54R, to transmitter units 42R, where these optical signals are launched into free space, as collimated beams of light, towards transceiver 36L. At transceiver 36L, the optical signals received by receiver units 44L are conveyed, via optical fibers 52L and 66L and combiner 56L, to receiver 62L of network interface unit 58L.

Clusters of transmitter units 42 are used in transmitter 38, and clusters of receiver units 44 are used in receiver 40, to overcome scintillation. Figure 3 shows transverse views of three different configurations of transceiver units 10 in clusters. Figure 3A shows three transceiver units 10 in a triangular configuration. Figure 3B shows four transceiver units 10 in a square configuration. Figure 3C shows seven transceiver units 10 in a hexagonal configuration.

Kostal et al., in U. S. Patent No. 4,960,315, teaches a similar system, for temporarily bridging a break in an optical fiber network. Because Kostal et al. base

their system on single transmitter and receiver units and on single mode optical fibers, they require an elaborate feedback mechanism to keep their transceivers aimed at each other. This feedback mechanism is not needed in the present invention, because the use of clusters of transmitter units and receiver units compensates for scintillation and beam wander, and because multimode optical fibers 20 of the present invention have wider divergence angles (order of 2 milliradians) than the very narrow divergence angles of the single mode optical fibers used by Kostal et al.

The system of Figure 2 is adequate for linking two parts of an optical communications network that are separated by distances up to several hundred meters. For communications across greater distances, the transmitted optical signals must be amplified. Figure 4 shows a variant 38' of transmitter 38 that includes optical amplifiers 70 and 71 for this purpose. In variant 38', each transmitter unit 42 is provided with its own optical amplifier 70. Each optical amplifier 70 is optically coupled to a respective transmitter optical fiber 50 at proximal end 51 of transmitter optical fiber 50 and to a respective optical amplifier input optical fiber 72 at the distal end 74 of optical amplifier input optical fiber 72. Optical amplifier input optical fibers 72 are optically coupled at the proximal ends 76 thereof to distal end 65 of common input optical fiber 64 by splitter 54 and a fourth, common optical amplifier 71. Common optical amplifier 71 is optically coupled to common input optical fiber 64 at distal end 65 thereof and to an optical amplifier output fiber 78 at the proximal end 82 thereof, and the distal end 80 of optical amplifier output fiber 78 is optically coupled to splitter 54. Note that optical amplifier 71 is optional. The optical fibers leading into and out of an optical amplifier 70 must be single mode optical fibers. Therefore, transmitter units 42 must be variants B of transceiver units 10.

Optical amplifiers 70 typically are erbium-doped fiber amplifiers or semiconductor optical amplifiers.

Although the transfer of optical signals from a single-mode optical fiber to a multimode optical fiber is energetically efficient, this is not the case for transfer of optical signals from a multimode optical fiber to a single mode optical fiber. Therefore, it is preferred that receiver units 44 be variants A of transceiver units 10, and that optical fibers 52 and 66 be multimode optical fibers. If receiver 62 of a

network interface unit 58 is configured to receive single mode input, receiver 62 must be provided with a passive adapter 68, as shown in Figure 2 for network interface unit 58L, to provide efficient optical coupling of common output optical fiber 66 to receiver 62. Examples of suitable passive adapters 68 include graded index lenses and collimators.

Figure 5 shows an alternate transceiver 84 of the present invention, optically coupled to network interface unit 58. Transmitter 60 of network interface unit 58 is optically coupled by a transmitter optical fiber 86 to a transmitter 38 of the type discussed above. Receiver 62 of network interface unit 58 is optically coupled by a receiver optical fiber 88 to a converter unit 90 that is substantially identical to TXU 20 of US 5,818,619. Converter unit 90 is in turn electronically coupled to an airlink receiver 92 by a suitable connector 96. Optical signals intercepted by airlink receiver 92 are converted to electronic signals and relayed to converter unit 96, which converts the electronic signals back to optical signals, as described in US 5,818,619.

In Figure 5, dashed line 46 represents the optical axis of a single transmitter unit 42, if transmitter 38 includes only one transmitter unit 42, or the parallel optical axes of all the transmitter units 42 of transmitter 38, if transmitter 38 includes more than one transmitter unit 42. Airlink receiver 92 also has an optical axis, indicated by reference numeral 94. Optical axes 46 and 94 are parallel.

Transceiver 84 is used in the same way as transceiver 36 to link two different parts of an optical communications network.

The systems of the present invention may be substituted for the system described in US 5,818,619 in any of the applications of the latter system. The systems of the present invention also may be used to exchange DWDM signals between two widely separated parts of an optical communications network. Figure 6 is a partial schematic illustration of a system of the present invention configured for this purpose. At the transmitting location, transmitter 38L receives DWDM optical signals from transmitter 60L of network interface unit 58L via an optical fiber 64L and launches those signals as a collimated light beam 104 towards receiver 40R at the receiving location. Preferably, transmitter 38L is one of the variants of a transmitter of the present invention that includes one or more optical amplifiers 70, as discussed above,

and optical fiber 64L is a single mode optical fiber. Receiver 40R is optically coupled to a demultiplexer 98 by a multimode optical waveguide 104. Demultiplexer 98 directs each of the incoming carrier wavelengths to a respective channel that includes a detector 100 for converting the optical signals carried on that carrier wavelength to electronic signals and an amplifier 102 for amplifying the electronic signals from the  
5 respective detector 100.

The definition of a network interface unit 58, as understood in the context of the present invention, is broader than in US 5,818,619. In particular, network interface unit 58 may be an RF-optical transceiver, such as the SAT-LIGHT 2000  
10 transceiver available from Foxcom Ltd. of Jerusalem, Israel, that is used for converting RF analog signals to optical signals and vice versa. Conventionally, these optical signals are exchanged between two separate locations via optical fibers. The present invention enables these transceivers to be used to exchange optical signals between two separate locations without laying optical fibers between the two  
15 locations. One important application of this is in cellular telephony. It often is desirable to locate a cellular telephony base station antenna at a considerable distance from the other base station hardware. The present invention allows this to be done without laying optical fibers between the base station and the base station antenna, thereby allowing enhanced flexibility in the siting of the base station antenna.

As is well known to those skilled in the art, the preferred optical amplifiers 70  
20 and 71 for a transmitter 38' intended for the transmission of RF analog signals are not the preferred optical amplifiers 70 and 71 that are used for digital applications such as DWDM. The optical amplifiers 70 and 71 that are used in analog applications must have enhanced linearity. Erbium-doped fiber amplifiers of suitable linearity are  
25 commonly used in CATV applications.

While the invention has been described with respect to a limited number of embodiments, it will be appreciated that many variations, modifications and other applications of the invention may be made.

## WHAT IS CLAIMED IS:

1. An optical device comprising:
  - (a) a multimode optical waveguide having a proximal end and a distal end;
  - (b) a single mode optical waveguide having a distal end;
  - (c) a mechanism for optically coupling said distal end of said single mode optical waveguide to said proximal end of said multimode optical waveguide; and
  - (d) imaging optics, optically coupled to said distal end of said multimode optical waveguide.
2. The optical device of claim 1, wherein said mechanism includes a FC/APC fiber optic connector.
3. The optical device of claim 1, further comprising:
  - (e) a mechanism for suppressing reflections at said distal end of said multimode optical waveguide.
4. The optical device of claim 3, wherein said mechanism for suppressing reflections includes a FC/APC fiber optic connector.
5. An optical transmitter, comprising:
  - (a) a common input optical waveguide;
  - (b) a plurality of transmitter optical waveguides, each said transmitter optical waveguide having a distal end;
  - (c) for each said transmitter optical waveguide, imaging optics, optically coupled to said distal end of said each transmitter optical waveguide; and
  - (d) a mechanism for optically coupling said common input optical waveguide to said transmitter optical waveguides.

6. The optical transmitter of claim 5, further comprising:
- (e) for each said transmitter optical waveguide, an optical amplifier, optically coupled to said each transmitter optical waveguide.

7. The optical transmitter of claim 6, wherein said optical amplifiers are selected from the group consisting of erbium-doped fiber amplifiers and semiconductor optical amplifiers.

8. The optical transmitter of claim 6, further comprising:
- (f) for each said optical amplifier, an amplifier input optical waveguide, optically coupled to said each optical amplifier;

and wherein said mechanism includes a splitter for optically coupling said common input optical waveguide to said amplifier input optical waveguides.

9. The optical transmitter of claim 8, wherein said transmitter optical waveguides are multimode optical waveguides, the optical transmitter further comprising:

- (g) for each said optical amplifier:
- (i) a single mode amplifier output optical waveguide, and
- (ii) a mechanism for coupling said amplifier output optical waveguide to a respective transmitter optical waveguide.

10. The optical transmitter of claim 9, wherein said mechanism for coupling said amplifier output optical waveguide to said respective transmitter optical waveguide includes a FC/APC fiber optic connector.

11. The optical transmitter of claim 5, wherein said mechanism includes a splitter.



12. The optical transmitter of claim 11, wherein said common input optical waveguide is a single mode optical waveguide and wherein said transmitter optical waveguides are multimode optical waveguides.

13. The optical transmitter of claim 11, further comprising:

- (e) an optical amplifier, optically coupled to said common input optical waveguide.

14. The optical transmitter of claim 13, wherein said optical amplifiers are selected from the group consisting of erbium-doped fiber amplifiers and semiconductor optical amplifiers.

15. An optical receiver, comprising:

- (a) a common output optical waveguide;
- (b) a plurality of receiver optical waveguides, each said receiver optical waveguide having a distal end;
- (c) for each said receiver optical waveguide, imaging optics, optically coupled to said distal end of said each receiver optical waveguide; and
- (d) a mechanism for optically coupling said common output optical waveguide to said receiver optical waveguides.

16. The optical receiver of claim 15, wherein said mechanism includes a combiner.

17. An optical transceiver comprising:

- (a) a transmitter optical waveguide having a distal end;
- (b) transmitter imaging optics, having a transmitter optical axis, optically coupled to said distal end of said transmitter optical waveguide;
- (c) a plurality of receiver optical waveguides, each said receiver optical waveguide having a distal end; and

- (d) for each said receiver optical waveguide, receiver imaging optics, having a receiver optical axis, optically coupled to said distal end of said each receiver optical waveguide, said transmitter optical axis and said receiver optical axes all being substantially parallel.

18. The optical transceiver of claim 17, further comprising:

- (e) a common output optical waveguide; and
- (f) a mechanism for optically coupling said receiver optical waveguides to said common output optical waveguide.

19. The optical transceiver of claim 18, wherein said mechanism includes a combiner.

20. A wireless communications system, comprising:

- (a) a transmitter optical waveguide having a proximal end and a distal end;
- (b) transmitter imaging optics, optically coupled to said distal end of said transmitter optical waveguide;
- (c) at least one receiver optical waveguide having a proximal end and a distal end;
- (d) for each said at least one receiver optical waveguide, receiver imaging optics optically coupled to said distal end of said at least one receiver optical waveguide; and
- (e) an optical communication network interface unit, optically coupled to said proximal ends of said transmitter optical waveguide and of said at least one receiver optical waveguide, for transmitting optical signals to said transmitter optical waveguide and for receiving optical signals from said at least one receiver optical waveguide.

21. The wireless communications system of claim 20, including a plurality of said receiver optical waveguides.

- 22. The wireless communications system of claim 21, further comprising:
  - (f) a combiner for optically coupling said proximal ends of said receiver optical waveguides to said network interface unit.
- 23. The wireless communications system of claim 22, further comprising:
  - (g) a passive adapter for optically coupling said combiner to said network interface unit.
- 24. The wireless communications system of claim 23, wherein said passive adapter is selected from the group consisting of graded index lenses and collimators.
- 25. The wireless communications system of claim 20, further comprising:
  - (f) for each said at least one receiver optical waveguide, a passive adapter for optically coupling said proximal end of said each receiver optical waveguide to said network interface unit.
- 26. The wireless communications system of claim 23, wherein said passive adapter is selected from the group consisting of graded index lenses and collimators.
- 27. An optical transceiver comprising:
  - (a) a transmitter optical waveguide having a distal end;
  - (b) transmitter imaging optics, having a transmitter optical axis, optically coupled to said distal end of said transmitter optical waveguide; and
  - (c) an airlink receiver having a receiver optical axis substantially parallel to said transmitter optical axis.
- 28. The optical transceiver of claim 27, further comprising:
  - (d) a converter unit, electrically coupled to said airlink receiver.
- 29. A wireless communication system, comprising:
  - (a) a transmitter optical waveguide having a proximal end and a distal end;

- (b) transmitter imaging optics, optically coupled to said distal end of said transmitter optical waveguide;
- (c) an airlink receiver;
- (d) a converter unit, electrically coupled to said airlink receiver; and
- (e) an optical communication network interface unit, optically coupled to said proximal end of said transmitter optical waveguide and to said converter unit, for transmitting optical signals to said transmitter optical waveguide and for receiving optical signals from said converter unit.

30. An optical device comprising:

- (a) an optical fiber having a distal end; and
- (b) a FC/APC fiber optic connector serving as a reflection-suppressing interface between said distal end and a rarefied optical medium.

31. A wireless system for transmitting wavelength-multiplexed optical signals from a first location to a second location, comprising:

- (a) an optical transmitter, at said first location, said optical transmitter including a multimode input optical waveguide for receiving the optical signals; and
- (b) an optical receiver, at said second location, for receiving the optical signals from said optical transmitter.

32. The system of claim 31, further comprising:

- (c) a single mode input optical waveguide, at said first location, said multimode input optical waveguide receiving the optical signals from said single mode input optical waveguide.

33. The system of claim 32, further comprising:

- (d) a mechanism for optically coupling said single mode input optical waveguide to said multimode input optical waveguide.

34. The system of claim 33, wherein said mechanism includes a FC/APC fiber optic connector.

35. The system of claim 32, further comprising:

- (d) an optical amplifier for receiving the optical signals from said single mode input optical waveguide; and
- (e) a mechanism for optically coupling said optical amplifier to said multimode input optical waveguide, so that said multimode input optical waveguide receives the optical signals from said single mode input optical waveguide via said optical amplifier.

36. The system of claim 35, wherein said mechanism includes:

- (i) a single mode output optical waveguide, receiving the optical signals from said optical amplifier; and
- (ii) a FC/APC fiber optic connector for coupling said single mode output optical waveguide to said multimode input optical waveguide.

37. The system of claim 35, wherein said optical amplifier is selected from the group consisting of erbium-doped fiber amplifiers and semiconductor optical amplifiers.

38. The system of claim 31, wherein said optical receiver includes a multimode output optical waveguide, the system further comprising:

- (c) a demultiplexer, optically coupled to said multimode output optical waveguide, for demultiplexing the optical signals.

39. A method for exchanging optical signals between two parts of an optical network, comprising the steps of:

- (a) providing each part of the network with:
  - (i) a network interface unit, and

- (ii) a transceiver including:
  - (A) transmitter imaging optics,
  - (B) at least one transmitter optical waveguide for optically coupling said network interface unit to said transmitter imaging optics,
  - (C) receiver imaging optics, and
  - (D) at least one receiver optical waveguide for optically coupling said network interface unit to said receiver imaging optics; and
- (b) aiming said transceivers so that at least part of the optical signals emerging from said transmitter imaging optics of a first said transceiver are intercepted by said receiver imaging optics of a second said transceiver and so that at least part of the optical signals emerging from said transmitter imaging optics of said second transceiver are intercepted by said receiver imaging optics of said first transceiver.

40. A method for exchanging optical signals between two parts of an optical network, comprising the steps of:

- (a) providing each part of the network with:
  - (i) a network interface unit, and
  - (ii) a transceiver including:
    - (A) transmitter imaging optics,
    - (B) at least one transmitter optical waveguide for optically coupling said network interface unit to said transmitter imaging optics,
    - (C) an airlink receiver, and
    - (D) a converter unit, electrically coupled to said airlink receiver and optically coupled to said network interface unit; and
- (b) aiming said transceivers so that at least part of the optical signals emerging from said transmitter imaging optics of a first said

transceiver are intercepted by said airlink receiver of a second said transceiver and so that at least part of the optical signals emerging from said transmitter imaging optics of said second transceiver are intercepted by said airlink receiver of said first transceiver.

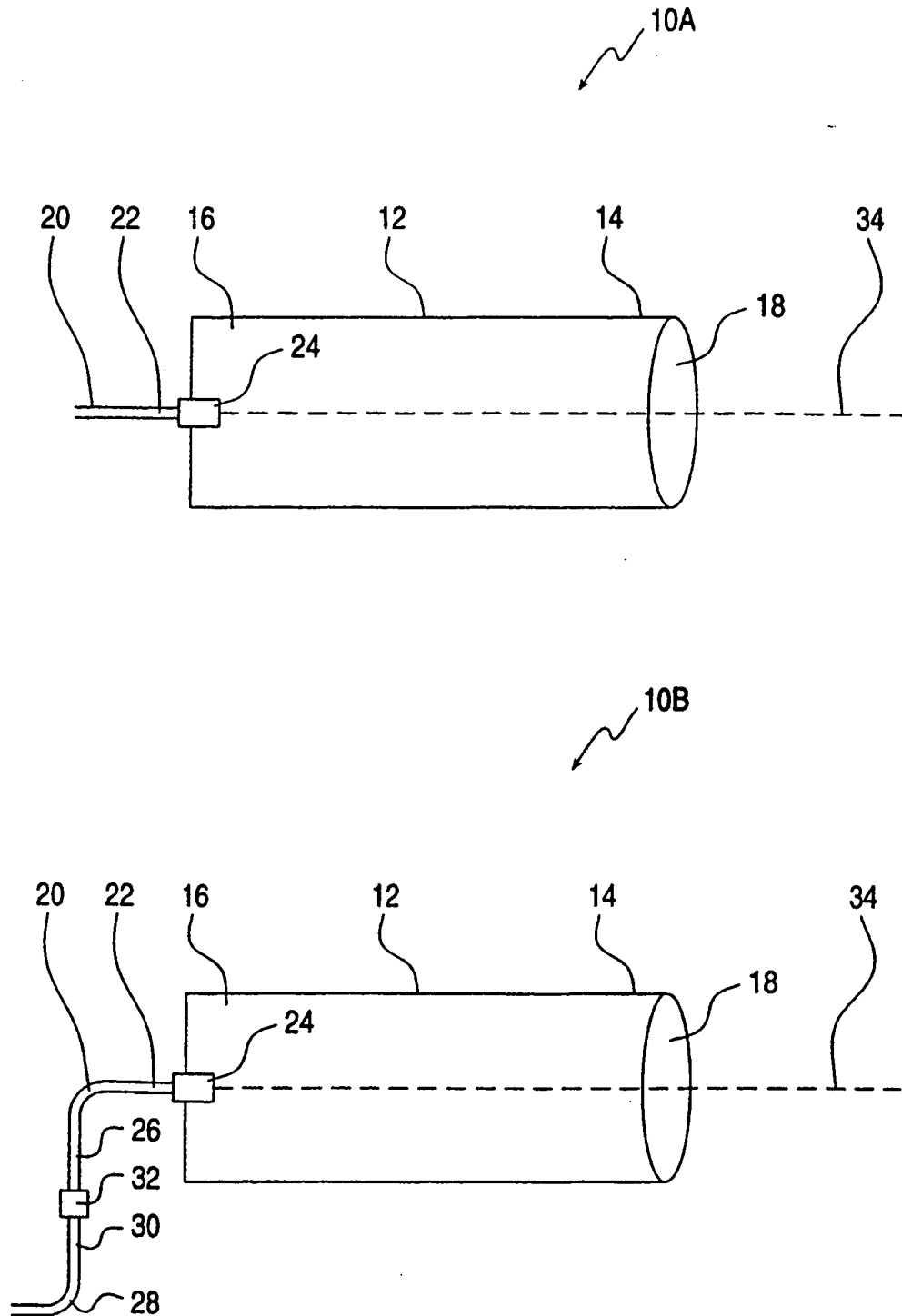


FIG.1



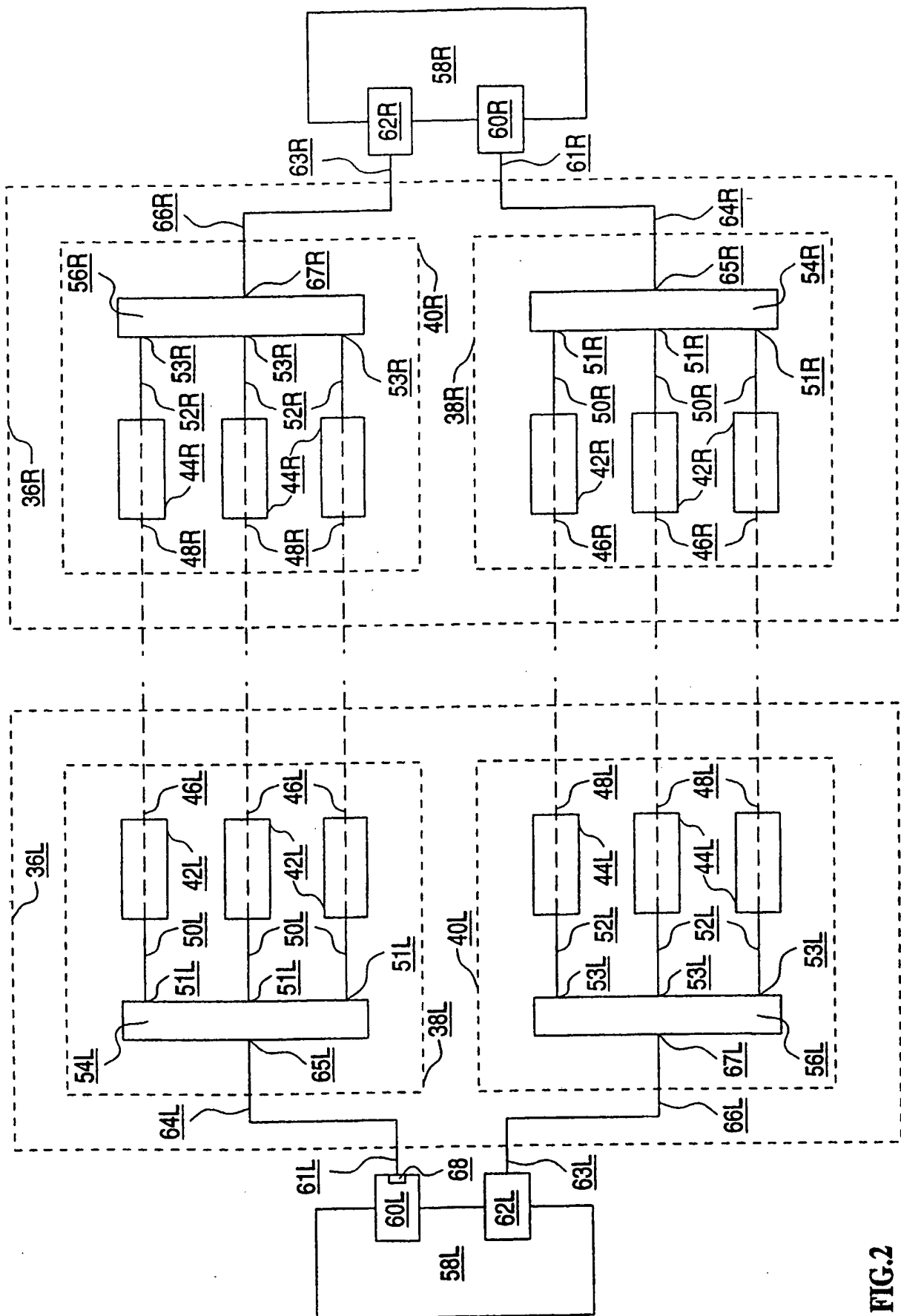
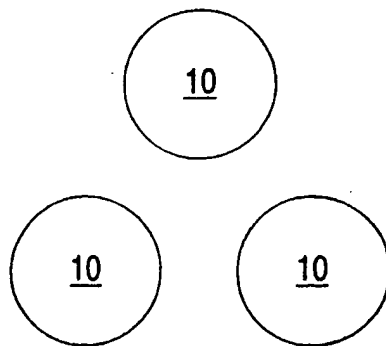
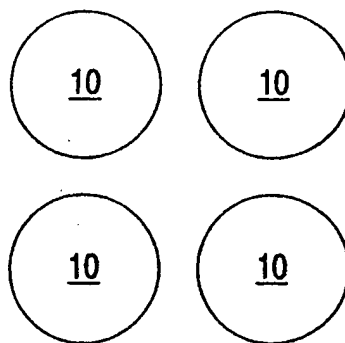


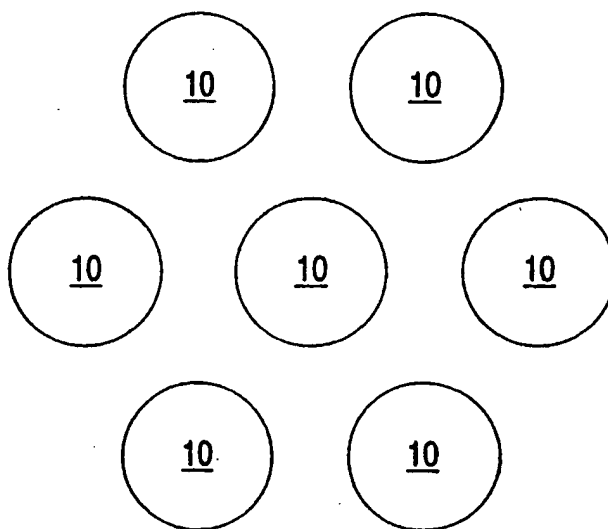
FIG. 2



**FIG.3A**



**FIG.3B**



**FIG.3C**

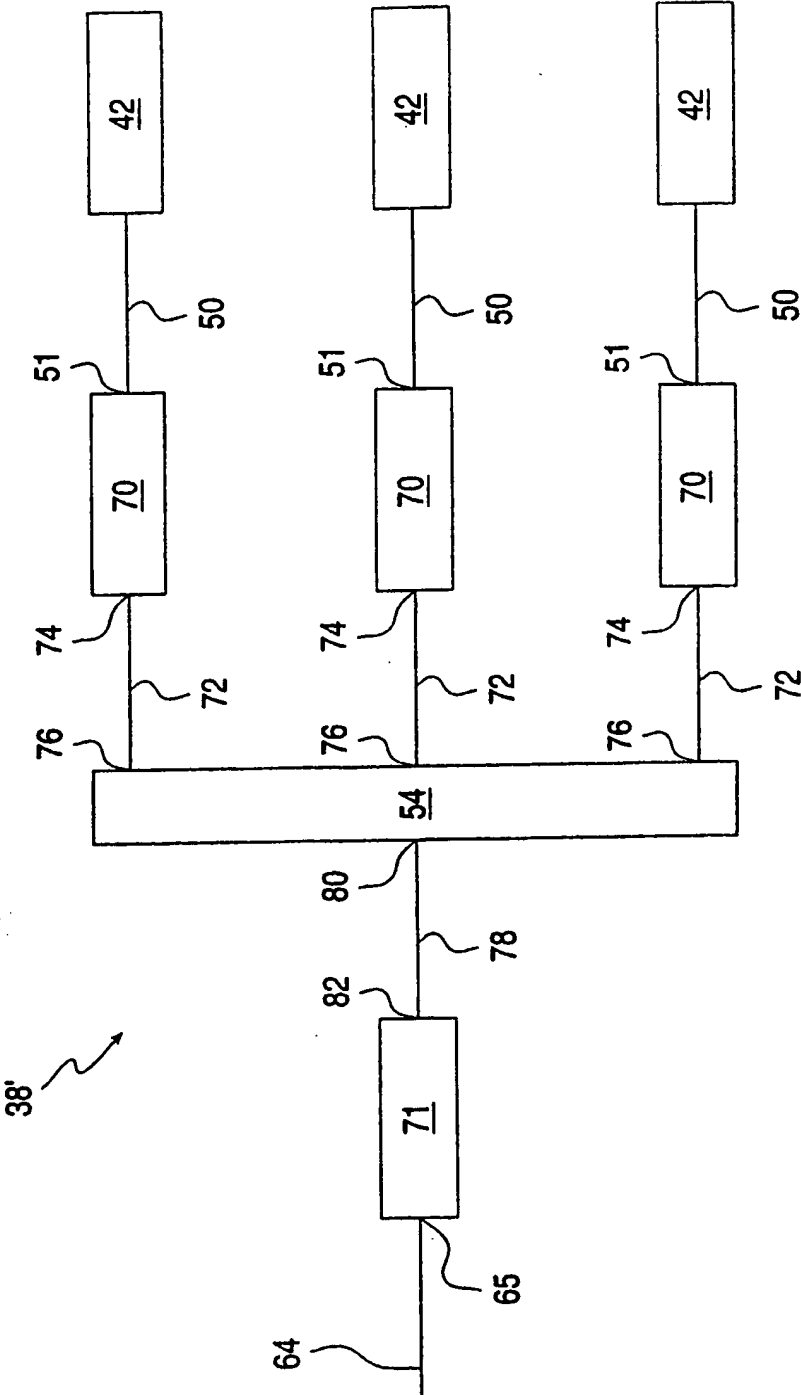


FIG.4

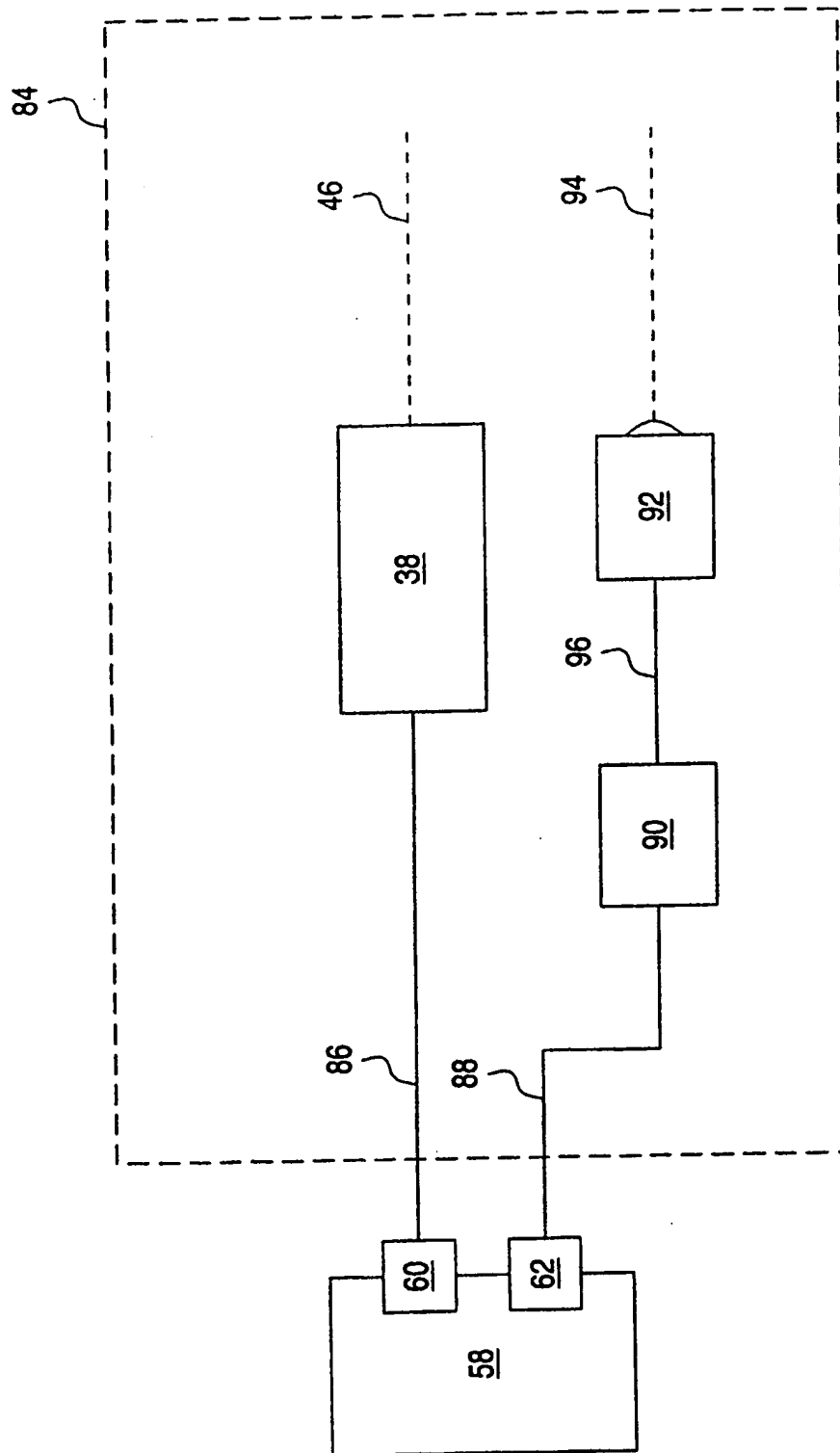


FIG.5

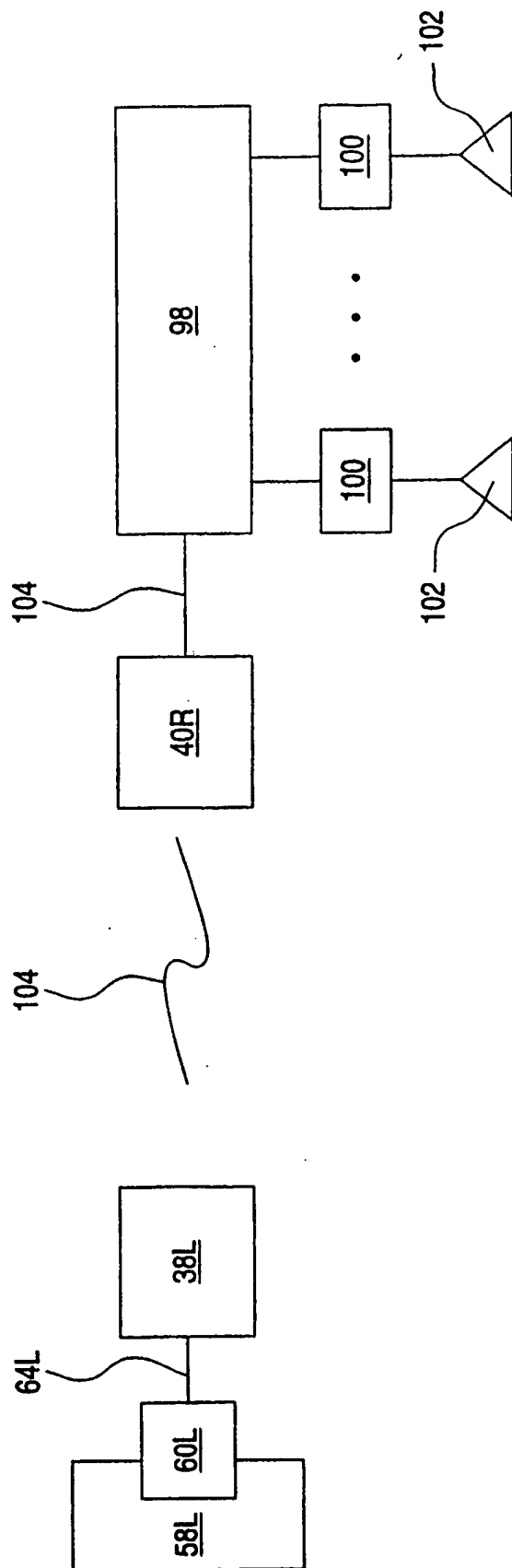


FIG.6

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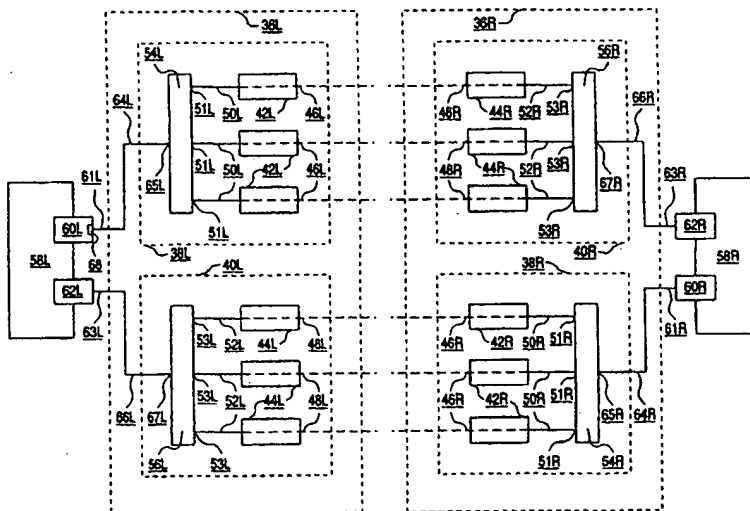
Published:

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20 September 2001

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: WIRELESS OPTICAL COMMUNICATIONS WITHOUT ELECTRONICS



(57) Abstract: A system for exchanging optical signals between two separate locations. Each location is provided with a transceiver (10) that includes a transmitter and a receiver. Both the transmitter and the receiver are based on a transceiver unit (10), used as a transmitter unit in the transmitter and as a receiver unit in the receiver. The transceiver unit (10) includes a multimode optical waveguide (20 & 28) and imaging optics that collimates the light emerging from the waveguide and imaging optics (18) that collimates the light emerging from the waveguide in the transmitter implementation of the unit. The waveguide is terminated by a FC/APC (24) to suppress reflections at the waveguide/air interface. The common waveguides in turn are optically coupled to network interface units (58) at each location. Transceivers are aimed at each other to exchange optical signals between the two locations.

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/IL99/00500

**A. CLASSIFICATION OF SUBJECT MATTER**IPC(7) : GO2B 6/26, 6/00  
US CL : 385/ 31, 39, 88, 147

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**Minimum documentation searched (classification system followed by classification symbols)  
U.S. : 385/ 31, 39, 88, 147

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
EAST**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,300,816 A (SNITZER et al) 17 November 1981 (17.11.1981) see the entire specification and figures 1 & 2	1-4 and 30
Y	US 3,932,162 A (BLANKENSHIP) 13 January 1976 (13.01.1976) see the entire document	1-4 and 30

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

Special categories of cited documents:	
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier application or patent published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

28 March 2001 (28.03.2001)

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# INTERNATIONAL SEARCH REPORT

International application No.

PCT/IL99/00500

## Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claim Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claim Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claim Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:  
Please See Continuation Sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.: 1-4 and 30

Remark on Protest

☐  
☐

The additional search fees were accompanied by the applicant's protest.

No protest accompanied the payment of additional search fees.



**BOX II. OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING** This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claim(s) 1-4 and 30, drawn to an optical device comprising a multimode optical waveguide having a proximal end and a distal end and a single mode optical waveguide having a distal end.

Group II, claim(s) 5-14, drawn to an optical transmitter comprising a common input optical waveguide and a plurality of transmitter optical waveguides.

Group III, claim(s) 15-19, drawn to an optical receiver comprising a common output optical waveguide and an optical transceiver having a transmitter optical waveguide having a distal end.

Group IV, claim(s) 20-29, drawn to a wireless communications system.

Group V, claim(s) 31-40, drawn to a wireless system for transmitting wavelength-multiplexed optical signals from a first location to a second location.

The inventions listed as Groups I - V do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: the claims of these five (5) groups are directed to different inventions which are not so linked to form a single general concept. The claims in the different groups do not have in common the same or corresponding "special technical features". In particular, Group I is an optical device having a multimode optical waveguide and a single mode optical waveguide where a mechanism includes a FC/APC fiber optic connector whereas Group II requires an optical transmitter comprising a common input optical waveguide coupled to a transmitter optical waveguide along with an amplifier which is consisted from the group of erbium-doped fiber; invention of Group III is an optical receiver or an optical transceiver couples with a mechanism which includes a combiner; Group IV is a purely a wireless communication system along with a network interface unit; Group V is directed to a wireless system for transmitting wavelength-multiplexed optical signals from a first location to a second location and a method of exchanging optical signals between two parts an optical network, i.e., a reference which anticipates or make obvious on of the inventions I - V-would not, by itself make an obvious any of the remaining invention. .